AN INTEGRATED SIMULATION MODEL FOR MANNING MAINTENANCE SHOPS

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ABSTRACT. An effective maintenance system is essential for organizations in order to meet their set objectives. These objectives include meeting deadlines, minimal delays, minimal repair turntime, and effective utilization of maintenance resources. In this paper the elements of an integrated simulation model has been described. The integrated model consists of several modules. These are planning and scheduling, organization, supply, quality control and performance measures. The required data and software for such a model has been described. The model has been tested and applied at the mechanical section at King Fahd University of Petroleum and Minerals maintenance department to determine their manning level. The results showed that the manning level at the mechanical shop are far from the optimal level according to the criteria used. Also the results of this study can be used as an initial input to investigate the manning levels at the maintenance department.

Keywords: Stochastic simulation; Maintenance systems; Mechanical; Manning

1. INTRODUCTION

Maintenance is an essential function for quality service that includes reliable schedules, meeting planned targets for service and minimizing delays. The role of maintenance in the long term profitability of an organization has been realized in the past, but until recently little attention has been given to modeling maintenance systems, [5]. Possible reasons include:

- Traditionally maintenance has been regarded as a necessary evil and at best a secondary system driven by production.
- Maintenance in an organization has complex relationships with other functions.
- The outputs of maintenance are difficult to define and measure.

In many production and service organizations it is essential to treat maintenance and operations as one system, due to the high degree of dependency between them. Several researchers have realized the dependency between maintenance and production and have developed simulation models to investigate the impact of maintenance on production. The impact is performed using production measures such as throughput rate, work in process and back order. The case for service industry is quite different than production systems in terms of organization and measures of performance used. In service industry a need exists to develop models that relate maintenance to the quality of service provided by the organization.

Stochastic simulation [6] is the process of representing a system on the computer and based on well designed experiments the system performance can be evaluated. This approach has been applied intensively in production systems as compared to maintenance. The problem of representing operation and maintenance as a one integrated system is complex in nature and therefore stochastic simulation offers a viable alternative for its modeling and analysis.

Maintenance functions has the following characteristics which make stochastic simulation as one of the most desirable approaches for their modeling and analysis. These characteristics have been identified as:

- Maintenance as a function interacts with other technical and engineering functions in a complex fashion.

- The maintenance factors are highly dependent on each other.

- Maintenance as a function has many uncertain elements. These elements include demand for maintenance, time of arrival of job requests, job content, time to complete a job and equipment and spare parts availability.

Simulation has been used for modeling maintenance operations. Each of these models dealt with a certain aspect of maintenance. The simulation models in maintenance has been classified according to maintenance activities. These activities are maintenance organization, planning and scheduling, spare parts and material management, shutdown policies. Several papers in the literature had modeled these aspects of maintenance [1,2,3,4,7,8,10,11,13,14].

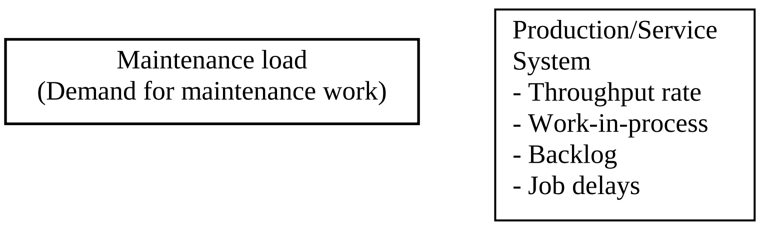
Most models in the literature dealt with a specific activity of maintenance. A need exists to integrate all aspects of maintenance and tie it with operations goals and objectives.

In this paper we propose a simulation model that integrates maintenance activities and operations. The integrated model consists of several modules. Each module represents a maintenance activity. The modules are linked together through the interactions of these activities. The heart of the integrated simulation model is the planning and scheduling module. This module links the other modules through the planning and scheduling of maintenance jobs. The other modules in the integrated model are: organization, supply, quality control and performance measures.

The rest of the paper is organized as follows. Section 2 outlines the elements of the integrated simulation model for maintenance. Section 3 describes the model utilization and its data requirements. Section 4 test and apply the model in a mechanical section of the a maintenance department at King Fahd University of Petroleum and Minerals. Section 5 concludes this paper.

2. AN INTEGRATED SIMULATION MODEL

In this section an integrated simulation model for maintenance operations will be outlined. The model integrates the objectives of operation and service with the maintenance activities. The model is structured in several modules. These modules include planning and scheduling, supply, quality control, maintenance organization and performance measures. Figure 1 shows a conceptual framework for the integrated simulation model. Next a brief description of each module is given.



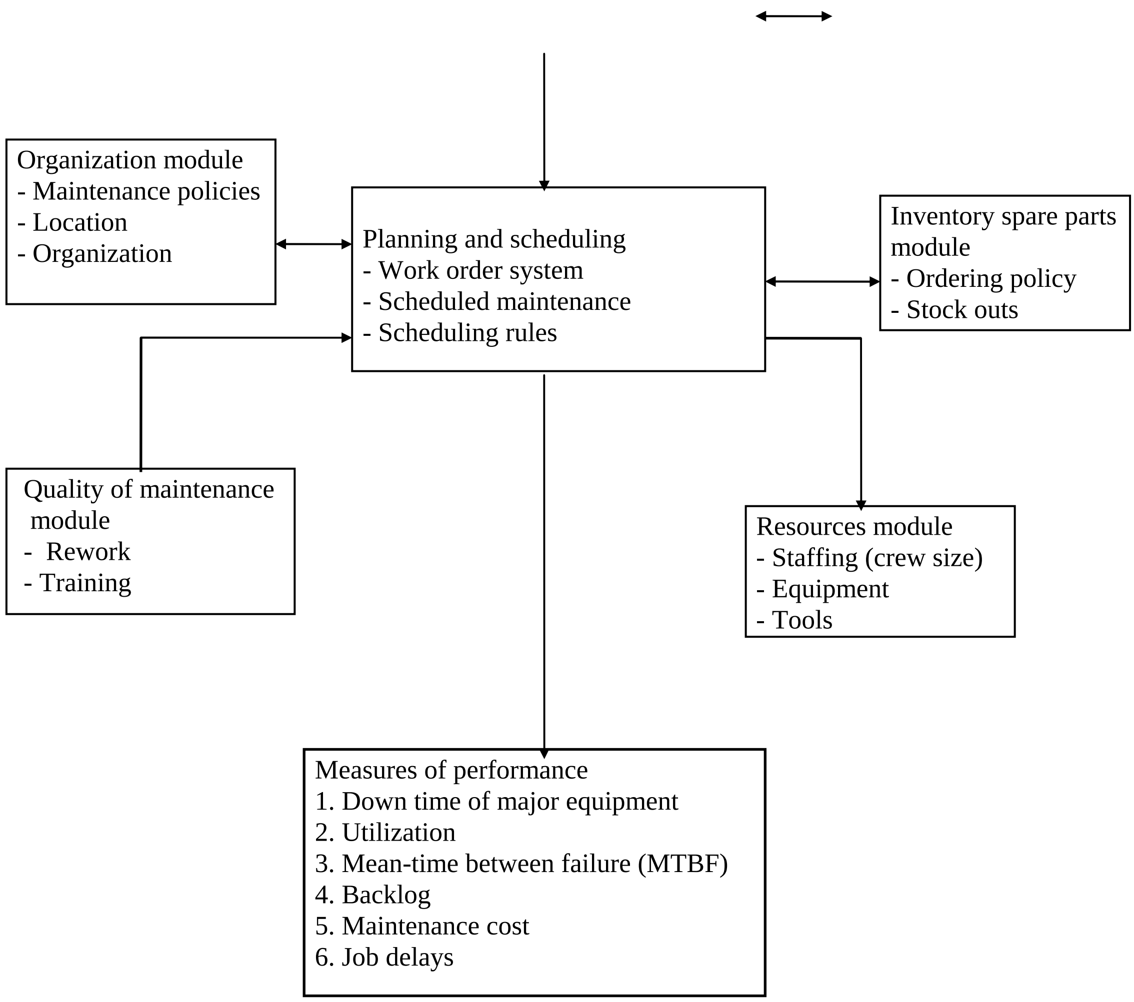


Figure 3. Elements of an Integrated Simulation Model for Maintenance

2.1 Planning and Scheduling Module

This module is the heart of the integrated simulation model. Its major function is to:

1. track equipment and plan and schedule their preventive maintenance,
2. monitor and schedule equipment inspection
3. plan and schedule maintenance work ,
4. monitor and control maintenance backlog.

In the process of planning and scheduling maintenance work, several tasks must be performed. These include:

1. Checking the service schedule,
2. Coordination with different repair stations,
3. Checking availability of spares,
4. Checking the availability of manpower and special equipment for maintenance

Then the resources of maintenance are matched with the demand for maintenance to achieve planned level of service. Using information from this module various measures of performance can be computed in order to evaluate the effectiveness of the maintenance system and its capability in meeting operation or service requirements. Possible measures of performance are: availability of service, percent delayed service, percent of scheduled maintenance to unscheduled maintenance, down time of major equipment, manpower productivity and maintenance costs.

2.2 Supply and Inventory Module

In large service organizations such as universities, utility functions inventory plays a key role in providing support for maintenance. In addition, organization in Saudi Arabia are relatively far from the sources of spare parts supply and that may require optimal policies for inventory and maintenance control. This module simulates different inventory policies used for stocking spare parts and material. This module is derived by the demand for spare parts by maintenance jobs. The effect of the ordering policy on maintenance backlog can be investigated and optimal ordering policies that minimizes the total inventory cost can be obtained using this module within the integrated simulation model.

2.3 Quality Control Module

The quality of maintenance work has a tremendous impact on the quality of service. Effective quality control procedures and standards need to be developed. The quality control module tracks the quality of maintenance jobs with its standard and can be used to identify needs for training by examining the percent rework for each crafts.

2.4 Organization Module

The organization module specifies the maintenance organization, its policies, available resources and its configuration. Given a certain maintenance organization and policies the simulation model can evaluate the capabilities of this organization and policies in meeting maintenance requirements. The model can evaluate several scenarios using measures of performance such as order cancellations, manpower utilization and maintenance backlog. The planning and scheduling module interface with this module for planning and scheduling maintenance jobs.

2.5 Performance Measures Module

The purpose of this module is to interface with other modules in order to collect statistics and compute values for various performance measures. Each time a statistics is collected, this module is called, and data is accumulated. After the run time of the simulation model is completed, this module is called to calculate various measures of performance. Usually they are four types of measures that need to be incorporated in the simulation model. The first type is performance measures such as maintenance cost per unit maintained, percentage orders canceled, orders delays due to maintenance. The second type of reports deal with equipment reliability such as major equipment down time, the third type deals with maintenance effectiveness such crafts utilization, crafts productivity, inventory cost. The fourth type deals with cost measures such as cost of maintenance by crafts, trends in spare parts and material costs. In summary, this module provides indices about the performance and effectiveness of maintenance.

3. MODULE REQUIREMENTS AND ITS UTILIZATION

In order for the model to be used the following data and software is needed.

1. Inspection schedules for each type of equipment,
2. Preventive maintenance schedules for equipment,
3. Preventive maintenance of auxiliary equipment,
4. Failure data on auxiliary items,
5. Element of the maintenance organization
6. Data on demand for spare parts,
7. Policies for stocking spare parts.
8. Resources available for maintenance, this include the manning of repair stations and available equipment,
9. Statistical package such as STATGRAPH [12],
10. A simulation language such as Simulation Language for Alternative Modeling (SLAM II), [9]

The integrated simulation model has been applied to a section in the maintenance department. King Fahd University of Petroleum and Minerals. Specifically the integrated model is used to evaluate their current manning policies and spare parts procedures. The use and application of this model is the subject of next section.

4. APPLICATION OF THE INTEGRATED SIMULATION MODEL

The model described in the previous section has been used to evaluate the manning levels of the King Fahd University of Petroleum and Minerals (KFUPM) maintenance department, the application of the model and the results are presented in detail for the mechanical shop.

4.1 Model Implementation

The mechanical shop has 18 technicians. It is responsible for all types of mechanical work including welding and other mechanical jobs.

The maintenance department has a centralized work control office where work is screened, planned, and scheduled. The work is scheduled based on first in first out (FIFO) rule. The work is entered in a computer and then routed to the concerned shop.

The planning and scheduling module is used to generate the work for the mechanical shop and then use the FIFO rule to assign the maintenance work. The load for the mechanical shop is generated as follows. First the load for the whole maintenance department is generated. Then the load for the mechanical shop is 4 percent of the total maintenance work. The time to service a job (time of repair) is modeled using data from the shop and the distribution that fitted this data is a lognormal distribution with parameters μ=2.78 and σ=1.74 (where μ and σ are the mean and the standard deviation of the normal distribution obtained as the exponential function of the time to repair i.e. if X is lognormal, then $Y=e^x$ is normal)

The mechanical shop has three sections. These are generators, mechanics and welding. The generated work is divided between these sections according to frequency.

Mechanical Shop Div.	Division		
	Generators	Mechanics	Welding

percent of work	20%	40%	40%

The jobs that arrives at the mechanical shop are usually assigned to one technician or two. Seventy percent of the jobs are handled with a crew of size 2 and the rest are handled with one technician.

The planning and scheduling module operates as follows:

1. Jobs are generated for the whole maintenance department.

2. 4% of these jobs are mechanical.

3. The mechanical work is distributed among its three divisions according to the frequency of work to each shop.

4. The time the crew take on the job is lognormal distribution with parameters $\mu = 2.78$ and $\sigma = 1.74$. This has been obtained by fitting real data obtained from the shop on jobs completion time in hours.

5. Crew size is determined using the rule that 70% of the jobs are assigned to a crew of size 2, and the other 30% each job is handled by 1 technician.

The assignment of crew size is performed by generating from an empirical distribution with two values 1 and 2 with probabilities

x	1	2
$p(x)$	0.3	0.7

The spare part module tracks the availability of needed spare parts. The delays due to spare parts is modeled as an uniform distribution with parameters 1 and 3 i.e. U(1,3). The distribution data for the delay resulting from spare parts is in weeks.

The quality control module generates the accepted jobs (good quality) as a percentage of performed jobs using historical quality levels. For example if in every 100 jobs 5 are repeatable or considered substandard jobs, the percentage of accepted or quality jobs is 95%.

The performance measured used are utilization of work force, job delays and backlog. The model is implemented using SLAM II simulation language.

The model has been validated by running it under the current conditions and obtaining the delays and weekly backlog. These two measures are compared with the current experienced delays and backlog and find to be very close.

4.2 Experimental Design and Result Analysis

In this section the set of experiment design and the results obtained are presented. The experiments are designed based on the number of workers in each shop. Then for each experiment the number of replication (how many times the simulation model is run to obtain estimates for the performance measures) is determined. The number of replications is determined by running the model for selected values of runs (*n*) and computing the estimates of the performance measures for successive runs until there is no significant difference between successive estimates, then the minimum *n* satisfying this condition is the selected number of replications for each experiment..

4.2.1 Suggested Experiments and Number of Replications

The proposed experiment consists of a manning levels of the mechanical shop. The proposed manning level are obtained by decreasing or increasing the current level of manpower at the shop one at a time with the limits given in the Table 1. For example the possible manning level for the mechanical shop ranges between 6±4.

Table 1. Ranges for Manning Level

No	**Shop**		
	Generators	Mechanical	Welding
Current No. of workers	6	6	6
Changes (−+)	3	4	2

The number of replications for each run was found to be 10 based on the procedure described in Section 4.2

4.2.2 Results and Analysis

The optimal level of manning is determined based on two performance measures. These are maximizing utilization of work force and minimizing maintenance backlog in hours. These are two conflicting criteria. The optimal levels for manning the mechanical shop are shown in Table 2.

Table 2. Optimal Manning Levels

Shop	Generators	Mechanical	Welding	Performance Measures Value		
				Utilization	Backlog in hours	Delay in hours
Current levels	6	6	6	61%	32.2%	16.8
Optimal level maximizing utilization	3	3	3	77%	36.13	13.64
Optimization level minimizing the backlog	6	4	3	69%	35.8	15.6

The results indicate that the manpower levels for both criteria are very far from the current manning level. The results of this model constitutes a initial input to investigate the process by which the manning level is determined at the maintenance shops at King Fahd University of Petroleum and Minerals.

5. CONCLUSION

In this paper the elements of an integrated simulation model for the maintenance system at service organizations is proposed and implemented using SLAM II. The integrated simulation model consists of several modules that represent the maintenance activities. The modules are linked through the interaction of the maintenance activities. The modules are planning and scheduling, maintenance organization, supply, quality control and performance measures. The requirements needed to make such a model operational has been specified. The model has been demonstrated on a mechanical shop at KFUPM which a reasonable example of a service organization. The model indicated that the current manning level for both criteria are far from the current manning level. The results of the model constitutes an initial input to investigate the manning levels and the organization of the maintenance department. The model is effective in evaluating existing maintenance system and designing new one.

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